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THESIS

FEASIBILITY ANALYSIS AND PROTOTYPING OF A FAST AUTONOMOUS RECON SYSTEM

by

Marcus A. Torres

June 2017

Thesis Advisor:	Oleg A. Yakimenko
Second Reader:	Fotis A. Papoulias

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The United States Marine Corps (USMC) would like to have real-time intelligence, surveillance and reconnaissance (ISR) data about a landing zone (LZ) prior to the aircraft entering its terminal phase of flight. This thesis provides a feasibility analysis and prototyping of a fast autonomous recon system. Field tests were conducted in the Mojave Desert using a delivery system ("1/2 scale Patriot Missile" rocket kit) and two aerodynamic test sets (ATS); the delivery system and test sets were constructed by modifying commercial-off-the-shelf products. Two launches were conducted; the data obtained from the altimeters determined that the ATSs experienced large amounts of g-force upon their initial acceleration and landing. The use of a missile or rocket to propel the system will allow for increased range and extended on-station time. Additionally, the Fast Intelligence, Surveillance, and Reconnaissance (FASTISR) system could be used to increase the flexibility of certain units that require ISR on their missions, instead of waiting for in-theater assets. Utilizing a missile or rocket does come with some increased risks The FASTISR system must be designed and built to withstand the increased g-forces. The conclusion is that the USMC could employ such a technology.

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FEASIBILITY ANALYSIS AND PROTOTYPING OF A FAST AUTONOMOUS RECON SYSTEM

Marcus A. Torres
Lieutenant, United States Navy
B.S., Embry-Riddle Aeronautical University, 2007

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Approved by: Oleg A. Yakimenko
Thesis Advisor

Fotis A. Papoulias
Second Reader

Ronald E. Giachetti
Chair, Department of Systems Engineering

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ABSTRACT

The United States Marine Corps (USMC) would like to have real-time intelligence, surveillance and reconnaissance (ISR) data about a landing zone (LZ) prior to the aircraft entering its terminal phase of flight. This thesis provides a feasibility analysis and prototyping of a fast autonomous recon system. Field tests were conducted in the Mojave Desert using a delivery system ("1/2 scale Patriot Missile" rocket kit) and two aerodynamic test sets (ATS); the delivery system and test sets were constructed by modifying commercial-off-the-shelf products. Two launches were conducted; the data obtained from the altimeters determined that the ATSs experienced large amounts of g-force upon their initial acceleration and landing. The use of a missile or rocket to propel the system will allow for increased range and extended on-station time. Additionally, the Fast Intelligence, Surveillance, and Reconnaissance (FASTISR) system could be used to increase the flexibility of certain units that require ISR on their missions, instead of waiting for in-theater assets. Utilizing a missile or rocket does come with some increased risks The FASTISR system must be designed and built to withstand the increased g-forces. The conclusion is that the USMC could employ such a technology.

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LIST OF ACRONYMS AND ABBREVIATIONS

AA	air-to-air
AGL	above ground level
AOA	analysis of alternatives
AS	air-to-surface
ASL	above sea level
ATS	aerodynamic test set
CJTF-HOA	Combined Joint Task Force-Horn of Africa
CAD	computer-aided-drafting
COTS	commercial-off-the-shelf
DoDAF	Department of Defense Architecture Framework
EO	electro-optical
FAR	Friends of Amateur Rocketry, Inc.
FASTISR	Fast Intelligence, Surveillance, and Reconnaissance
FBL	functional baseline
GPS	global positioning system
INCOSE	International Council on Systems Engineering
IR	infrared
ISR	intelligence, surveillance, and reconnaissance
LZ	landing zone
NAVAIR	Naval Air Systems Command
NPS	Naval Postgraduate School
ONR	Office of Naval Research
RISTA	reconnaissance, intelligence, surveillance and target acquisition
STEM	science, technology, engineering, and mathematics
UAS	unmanned aerial system
UN	United Nations
USMC	United States Marine Corps
USMCWL	United States Marine Corps Warfighting Laboratory
VTOL	Vertical Takeoff and Landing

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EXECUTIVE SUMMARY

The Marines onboard the V-22 aircraft would like to have real-time intelligence, surveillance and reconnaissance (ISR) data about a landing zone (LZ) prior to the aircraft entering its terminal phase of flight. They want the system to be capable of reaching the LZ ahead of V-22, loitering above the LZ, and transmitting LZ ISR data back to the V-22 for at least eight minutes prior to LZ arrival.

This requirement emerged when the U.S. Marine Corps learned that three U.S. Air Force V-22 aircraft were engaged by anti-aircraft and small arms weapons on their approach to an LZ in the South Sudan (Church 2015). Even though the LZ was determined clear by the lead aircraft, the three aircraft and 34 aircrew were almost lost.

Currently, the V-22 aircraft does not have a method for deploying an UAS; however, an article in the written by Joshua Stewart (2014) for the *Marine Corps Times* states that the Officials at Headquarters Marine Corps are considering arming and installing the V-22 with greater weapons capability. In the article, Loren Thompson, the chief operating officer of the Lexington Institute, mentions that the V-22 aircraft could be easily modified with hardpoints, the devices utilized to carry missiles on the outside of aircraft (Stewart 2014).

Based upon the data collected from field tests, it is the author's opinion that the V-22 aircraft could indeed utilize a fast intelligence, surveillance, and reconnaissance (FASTISR) system. A FASTISR system is considered similar to a traditional unmanned aerial system (UAS) with the added benefit of being rocket or missile propelled. The expected cost of a single FASTISR system would be proportional to the existing or new missile system utilized, which typically cost hundreds of thousands of dollars. However, the cost would still be less than losing a single V-22 aircraft of $89 million (Church 2015).

This assessment can be utilized as a baseline to complement the inadequacies of current Group One UASs. The use of a missile or rocket to propel the system will allow for increased range and extended on-station time. Additionally, the FASTISR system

could be used to increase the flexibility of certain units, which require ISR on their missions to bring it with them instead of waiting for in-theater assets.

Field tests were conducted using a delivery system and two aerodynamic test sets (ATS). The delivery system constructed was a modified "1/2 Scale Patriot Missile" rocket kit manufactured by Public Missiles, Ltd. Similarly, a UAS was not purchased; instead, two ATS were constructed. The first ATS was constructed by modifying a Mighty Mini Sportster manufactured by Flite Test. The second ATS was constructed using reclaimed parts from a children's kite and the Mighty Mini Sportster. While both test sets may differ, each encompassed the same four components: airframe, GPS, altimeter, and camera.

Field tests were conducted at the Friends of Amateur Rocketry launch site in the Mojave Desert. Two launches were conducted; the first was with the glider ATS and second was with both the glider and flying-wing ATS. Altimeter and audio/video data was recovered when possible. The data from the altimeter was analyzed by custom script created within MATLAB.

Utilizing MATLAB to parse the data, results showed that the glider ATS experienced 18.03 times the normal force of gravity (g) in its initial acceleration from the delivery system. The ATS also experienced its maximum g-force of 22.19 g upon its landing. Inspection of the ATS showed that the entire system experience minor cosmetic damage; subsequently, it was reusable for further testing.

While a missile or rocket may increase the range and on-station time, it does come with some risks not previously associated with these systems, specifically, the launching mechanism. Group One systems are typically hand-launched and do not experience the same forces associated with a rocket launch. Field tests showed that initial rocket launch can be as much as 18 g from a small rocket motor, while this peak g-load cannot be representative for the AIM-120 missile, logic would dictate that a military system would be designed in such a way to combat the g-forces experienced from a military launch and subsequent maneuvering.

As a result, it is the author's opinion that the V-22 aircraft could indeed utilize a FASTISR system, assuming that it has been retrofitted to launch missiles or rockets.

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I. INTRODUCTION

A. BACKGROUND

In December 2013, several United States Air Force (USAF) V-22 aircraft were dispatched from Camp Lemonnier, Djibouti, to reinforce the U.S. embassy in the South Sudan capital of Juba. The V-22 aircraft were a part of the East Africa Response Force assigned to the Combined Joint Task Force-Horn of Africa (CJTF-HOA) for the region. Upon reaching the airport in Juba, the V-22 aircraft pilot found that the single runway was blocked and was forced to return to Camp Lemonnier. On the return flight, the V-22 aircraft received information that there were Americans located and surrounded by thousands of rebels in Bor, the capital of Jonglei (Church 2015).

After reaching the United Nations (UN) peacekeeping base, the three V-22 aircraft conducted a survey of the landing zone (LZ). The LZ was determined clear by the lead aircraft, Rooster 73. The V-22 aircraft started its landing approach and began taking anti-aircraft and small-arms fire. Although sustaining heavy damage, the three V-22 aircraft were able to save 34 aircrew and return to an alternate LZ. The cost associated with losing a single V-22 aircraft: approximately $89 million (Church 2015).

B. PURPOSE

The United States Marine Corps (USMC) currently utilizes the V-22 Osprey aircraft to conduct long-range missions. The Marines onboard the V-22 aircraft would like to have real-time intelligence, surveillance and reconnaissance (ISR) data about a LZ prior to the aircraft entering its terminal phase of flight. The Marines are considering the use of an unmanned aerial system (UAS) that will be capable of reaching the LZ ahead of V-22, loitering above the LZ, and transmitting LZ ISR data back to the V-22 for at least eight minutes prior to LZ arrival.

C. RESEARCH QUESTIONS

The purpose of this study is to present a conceptual design and evaluation of the Fast Intelligence, Surveillance, and Reconnaissance (FASTISR) system for the V-22 aircraft.

1. Primary Research Question

- How might the V-22 aircraft obtain ISR data about an LZ when in-theater assets are unable or unavailable?

2. Secondary Research Questions

- What are the current limitations of existing technologies?
- What are cost effective alternatives of the FASTISR system?

D. BENEFIT OF STUDY

This thesis will also provide preliminary prototyping and testing of a FASTISR system, which would allow V-22 aircraft to have the opportunity of acquiring real-time ISR over a landing zone when in-theater assets are unable to provide the necessary information. Implementing such a system would minimize loiter time while V-22 aircraft awaits ISR data, which would ultimately minimize risks and allow avoiding possible casualties in the case of ambush.

E. SCOPE

This work focuses on the beginning stages of the design process, which will include rapid prototyping of various ideas. The materials and solutions presented have emerged from rapid prototyping. Commercial-off-the-shelf (COTS) products and 3-D printed materials serve as the primary construction materials in design process.

F. METHODOLOGY

The systems engineering process serves as the baseline for the design and analysis of this body of work. This work addresses the system life-cycle stages and describes each stage. Table 1 addresses the different life-cycle stages and their purposes.

Table 1. Life-Cycle Stages and Their Purposes. Adapted from INCOSE (2012).

LIFE-CYCLE STAGES	PURPOSE
EXPLORATORY RESEARCH	Identify stakeholders' needs Explore ideas and technologies
CONCEPT	Refine stakeholders' needs Explore feasible concepts Propose viable solutions
DEVELOPMENT	Refine system requirements Create solution description Build system Verity and validate system
PRODUCTION	Produce systems Inspect and verify
UTILIZATION	Operate system to satisfy users' needs
SUPPORT	Provide sustained system capability
RETIREMENT	Store, archive, or dispose of the system

Table 2 addresses the systems process activities and interactions over the life cycle.

Table 2. Systems Process Activities and Interactions over the Life Cycle. Adapted from Blanchard and Fabrycky (2011).

CONCEPTUAL DESIGN	Problem Definition Need Identification Requirements Analysis Operational Requirements Maintenance and Support Concept	Evaluation of Technology Selection of Technical Approach Functional Definition of System System/Program Planning
PRELIMINARY DESIGN	Functional Analysis Program Implementation Requirements Allocation Trade-Off Studies Preliminary Design	Program Implementation Alternatives Acquisition Plans Contracting Preliminary Evolution of Design
DETAIL DESIGN AND DEVELOPMENT	Subsystem/Component Design Trade-Off Studies and Evaluation of Alternatives Development of Engineering and Prototype Models Verification of Manufacturing and Production Processes Developmental Test and Evaluation Supplier Activities Production Planning	
PRODUCTION/ CONSTRUCTION	Production and /or Construction of System Components Supplier Production Activities Acceptance Testing System Distribution and Operation Developmental/Operational Test and Evaluation Interim Contractor Support System Assessment	
OPERATIONAL USE AND SYSTEM SUPPORT	System Operation in the User Environment Sustaining Maintenance and Logistics Support Operational Testing System Modifications for Improvement Contractor Support System Assessment	

The system design process will encompass the concepts discussed in Tables 1 and 2. The concepts in this body of work are exploratory research, conceptual design, and preliminary design.

1. Exploratory Research

During this stage, the information from the stakeholders, the United States Marine Corps Warfighting Laboratory (USMCWL), was utilized to identify the needs of the service and explore ideas and technologies that are currently in place or may be utilized in the future.

2. Conceptual Design

This stage refines stakeholders' needs to determine the problem definition and identify specific needs and requirements for the system. Additionally, the functional definition of the system will be determined and a requirements analysis will be conducted.

3. Preliminary Design

During the preliminary design phase, a functional analysis was conducted for the system or systems that are going to be constructed. Alternatives to the system or systems constructed will be identified at this time. Upon completion of the functional analysis, a functional baseline (FBL) will be established.

G. THESIS ORGANIZATION

The second chapter of this thesis focuses on UASs and aircraft that are in use within the U.S. military. It also explores the problem formulation process and addresses key points in the design process. Chapter III consists of a conceptual design and a system feasibility study. Chapter IV covers the prototyping of the system; to include the design and construction of the aerodynamic test set (ATS). Chapter V describes field testing of the prototype.

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II. EXPLORATORY RESEARCH

This chapter discusses requirements gathered from the USMCWL. It identifies the needs of the service and explores ideas and technologies that are currently in place or may be utilized for the FASTISR concept.

A. REQUIREMENTS ANALYSIS

The USMCWL provided an initial description of the UAS and its capabilities as a self/air deployable UAS capable of dashing ahead of the V-22 aircraft to conduct final reconnaissance of LZ in order to update threat situation in route to the objective. The purpose of the UAS is to reduce tactical surprise to USMC assault forces on long-range missions. The goal is for the UAS to arrive at least eight minutes ahead of assault aircraft and provide a threat update on the objective for mission execution criteria.

The USMCWL has defined its requirements as follows:

- ISR system needs to be launched from V-22
- ISR system needs to provide LZ data at least eight minutes prior to V-22 arrival

Having identified the requirements of the system, capabilities and limitations of the V-22 aircraft and current UASs will be explored to determine if a system or systems can fulfill the proposed requirements.

B. V-22 "OSPREY" AIRCRAFT

The V-22 Osprey is joint service aircraft operated by the U.S. Marine Corps and U.S. Air Force. It is capable of takeoff, landing, and hovering like a helicopter but has the added benefit of high-speed flight similar to a fixed-wing aircraft. Figure 1 shows the two different flight modes of the V-22 aircraft.

The image on the left depicts the V-22 operating in hover mode. The image on the right depicts the V-22 operating in flight mode.

Figure 1. V-22 Osprey Aircraft Flight Modes. Source: Boeing (2017).

The V-22 aircraft is capable of completing a variety of missions from logistics to combat. It has the ability to refuel inflight and land in areas that do not require a runway. Although this aircraft can transit long ranges, it lacks the ability to carry missiles. The system's characteristics are shown in Table 3.

Table 3. V-22 Osprey Aircraft Characteristics. Adapted from Boeing (2017).

Primary Function	Vertical Takeoff and Landing (VTOL) Aircraft
Service Ceiling	25,000 feet
Cruise Speed	313 mph (272 knots)

A key parameter of the V-22 aircraft is its ability to fly as a fixed-wing aircraft thus achieving high-speed flight. This parameter is important when selecting candidate systems as it will determine if a disposable UAS is capable of reaching the desired location eight minutes prior to the V-22 aircraft.

C. CANDIDATE UNMANNED AERIAL SYSTEMS

The U.S. military operates multiple types of UASs depending on the mission profile. The United States Army and the United States Air Force use a classification system to separate UASs into different groups, as shown in Table 4.

Table 4. Joint UAS Group Classification. Source: U.S. Air Force (2009).

UAS Category	Maximum Gross Takeoff Weight (lbs.)	Normal Operating Altitude (ft.)	Speed (KIAS)	Current Representative UAS
Group 1	0-20	<1,200 AGL	100	Wasp III, TACMAV, RQ-14A/B, RQ-11B
Group 2	21-55	<3,500 AGL	<250	Scan Eagle, Silver Fox, Aerosonde
Group 3	<1320	<18,000 MSL		RQ-7B, RQ-15, XPV-1, XPV-2
Group 4	>1320		Any Airspeed	MQ-5B, MQ-1A/B/C
Group 5		>18,000 MSL		MQ-9A, RQ-4, RQ-4N

1. Group One Unmanned Aerial Systems

Group One UASs are predominantly hand-launched surveillance and reconnaissance systems. Most of these systems utilize a propeller propulsion system powered by an electric motor. These systems are very lightweight and typically fold for ease of transport.

a. Wasp III

The Wasp III is an UAS operated by the U.S. Air Force. (See Figure 2). Its primary mission objective is to provide real-time direct situational awareness and target information for U.S. Air Force Special Operations Command Battlefield Airmen (U.S. Air Force 2007).

Figure 2. Wasp III Unmanned Aerial System. Source: U.S. Air Force (2007).

The Wasp III is a hand-launched air vehicle with the ability to collapse for ease of transport by the operator. This system has been in operation since 2007 and is used extensively by the U.S. Army, U.S. Marine Corps, and the U.S. Air Force (U.S. Air Force 2007). The system's characteristics are shown in Table 5.

Table 5. Wasp III UAS Characteristics. Adapted from U.S. Air Force (2007).

Primary Function	Reconnaissance and Surveillance
Wingspan	28.5 inches (72.3 cm)
Length	10 inches (25.4 cm)
System Weight	14.4 pounds (6.53 kilograms)
Operating Altitude	1,000 feet
Speed	20-40 mph (17.3-34.7 knots)

b. BATCAM

The BATCAM, or TACMAV as it was previously called, is an UAS designed to meet the requirements of the special operations command. Its primary mission objective is to provide photographic imagery of an intended area. Figure 3 depicts the BATCAM UAS.

Figure 3. TACMAV Unmanned Aerial System.
Source: Defense Update (2009).

The TACMAV is a hand-launched air vehicle; however, instead of the wings folding, they wrap around the fuselage. This feature allows for storage within a tube and mounting on a backpack for ease of transport by the operator (Defense Update 2009). The system's characteristics are shown in Table 6.

Table 6. TACMAV UAS Characteristics. Adapted from *Defense Update* (2009).

Primary Function	Reconnaissance and Surveillance
Wingspan	26 inches (66.04 cm)
Length	10 inches (25.4 cm)
System Weight	15 pounds (6.80 kilograms)
Operating Altitude	200-500 feet
Speed	20-40 mph (17.3-34.7 knots)

c. Dragon Eye

The Dragon Eye, or RQ-14A, is an UAS designed to meet the requirements of the U.S. Marine Corps. Its primary mission objective is to collect real-time, high-resolution color or infrared images (National Air and Space Museum 2003). Figure 4 depicts the Dragon Eye UAS.

Figure 4. Dragon Eye Unmanned Aerial System. Source: U.S. Navy (2007).

The Dragon Eye is a hand-launched or bungee-launched air vehicle (Defense Update 2004). It reportedly has the ability to transmit live video up to a distance of 10 kilometers (6.2 miles). Additionally, it has the added feature of navigating predefined waypoints via its onboard global positioning system (GPS). Table 7 shows the system's characteristics.

Table 7. Dragon Eye UAS Characteristics. Adapted from *Defense Update* (2004) and National Air and Space Museum (2003).

Primary Function	Reconnaissance and Surveillance
Wingspan	45 inches (114 cm)
Length	36 inches (91 cm)
System Weight	5.9 pounds (2.7 kilograms)
Operating Altitude	<1,000 feet
Speed	40 mph (34.7 knots)

d. Raven

The Raven, or RQ-11B, is a UAS designed for military applications that required rapid deployment and high mobility (AeroVironment 2017). Its primary mission is to serve as a low-altitude surveillance and reconnaissance asset. Figure 5 depicts the Raven UAS.

Figure 5. Raven Unmanned Aerial System. Source: AeroViroment (2017).

The Raven is a hand-launched air vehicle (*Defense Update* 2004). Specifications indicate that it has the ability to transmit live video up to a distance of 10 kilometers (6.2 miles). Additionally, it has the added ability to use electro-optical (EO) / infrared (IR) camera with an IR illuminator. The system's characteristics are shown in Table 8.

Table 8. Raven UAS Characteristics. Adapted from AeroVironment (2017).

Primary Function	Reconnaissance and Surveillance
Wingspan	54 inches (140 cm)
Length	36 inches (91 cm)
System Weight	4.2 pounds (1.9 kilograms)
Operating Altitude	100-500 feet
Speed	20-50 mph (17.3-43.4 knots)

2. Group Two Unmanned Aerial Systems

Large Group Two systems, unlike group one, require a launching system; additionally, a more robust power plant must also be used. The power plant most commonly used in these systems is a gasoline or jet propellant fueled engine.

a. ScanEagle

The ScanEagle UAS designed for ISR missions on land or at sea (Insitu 2014). Its primary mission is to serve as a low-altitude surveillance and reconnaissance asset. Figure 6 depicts the ScanEagle UAS.

Figure 6. ScanEagle Unmanned Aerial System. Source: INSITU (2014).

The ScanEagle is a catapult launched air vehicle (U.S. Air Force 2009). The U.S. Air Force says that it has the ability to provide small vehicle resolution at distance up to five miles and act as a communication relay of encrypted and unencrypted radio transmissions. Additionally, the U.S. Air Force has assessed that it has a low altitude range of 68 miles. The system's characteristics are shown in Table 9.

Table 9. ScanEagle UAS Characteristics. Adapted from INSITU (2014).

Primary Function	Reconnaissance and Surveillance
Power Plant	Gas or Jet Propelled Motor
Wingspan	122.4 inches (311 cm)
Length	67.2 inches (155 cm)
System Weight	48.5 pounds (22 kilograms)
Operating Altitude	1,000-2,500 feet
Speed	57-70 mph (49.5-60.8 knots)

b. Silver Fox

The Silver Fox UAS was developed in cooperation with the Naval Air Systems Command (NAVAIR) and the Office of Naval Research (ONR). Its intended mission areas are reconnaissance, intelligence, surveillance and target acquisition (RISTA), battle damage assessment, littoral operations, harbor security, convoy protection, and perimeter security (Air Force Technology 2017). Figure 7 depicts the Silver Fox UAS.

Figure 7. Silver Fox Unmanned Aerial System. Source: Raytheon (2014).

The Silver Fox is launched using a closed-gas, piston, rail system (Air Force Technology 2017). Air Force Technology states that the onboard autopilot will allow the UAS to fly pre-programmed flight paths from takeoff to landing. Additionally, they claim that the drone has an operating range of 23 miles. The system's characteristics are shown in Table 10.

Table 10. Silver Fox UAS Characteristics. Adapted from Air Force Technology (2017) and Raytheon (2017).

Primary Function	Reconnaissance and Surveillance
Power Plant	Gas Engines and Electric Motors
Wingspan	94.4 inches (240 cm)
Length	57.8 inches (147 cm)
System Weight	28.6 pounds (13 kilograms)
Operating Altitude	500-1,200 feet
Speed	50-63 mph (43.4-54.7 knots)

3. Group Three and above Unmanned Aerial Systems

Group Three systems are typically larger than the Group Two and Group One systems. However, Group Three systems require the additional use of a runway because of their increased weight. Group Three and above systems are the type of systems that are available to Joint Commands and Task Forces. These systems also operate over a specific area, and moving assets from their assigned location takes significant planning. As a result, if they are not within a reasonable distance where a mission is being conducted, they are unable to reassigned to that location.

D. SUMMARY

The difference in size between Group One and Two systems allow for Group Two systems to carry more fuel and to use motors that are more powerful. These motors

increase the speed, range, and operating time of the systems. Additionally, moving up from one group will increase performance of the system, but it will also increase the cost of the system. This addition in cost could potentially determine whether or not the system is considered disposable or not. Additionally, neither Group One or Two systems are able to achieve an airspeed greater than that of the V-22; as a result, neither of these systems will reach the desired location eight minutes prior to the V-22's arrival. Therefore, an additional system must be used to bridge this capabilities gap.

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III. CONCEPTUAL DESIGN AND FEASIBILITY ANALYSIS

The USMCWL has stated that they want the ability for a V-22 aircraft to acquire ISR data about an LZ when in-theater assets are unavailable. The ability for the V-22 aircraft to obtain a cruise speed of 272 knots means an UAS would have to be traveling at speeds greater than that to arrive ahead of the V-22 and send back the data. Group One and Group Two UAS lack the range and speed required to accomplish such a mission. Group Three and above systems are the assets that unavailable to the V-22 when the need for LZ data is required.

Figure 8 is a time-distance plot for multiple airspeeds, which will show how fast, on average, a system needs to travel to meet the requirements set by the stakeholders. The criteria used in this figure are as follows:

- V-22 aircraft traveling at a constant cruise speed of 272 kts
- UAS launched at 75 nm from LZ
- UAS arrives at least eight minutes before V-22 aircraft

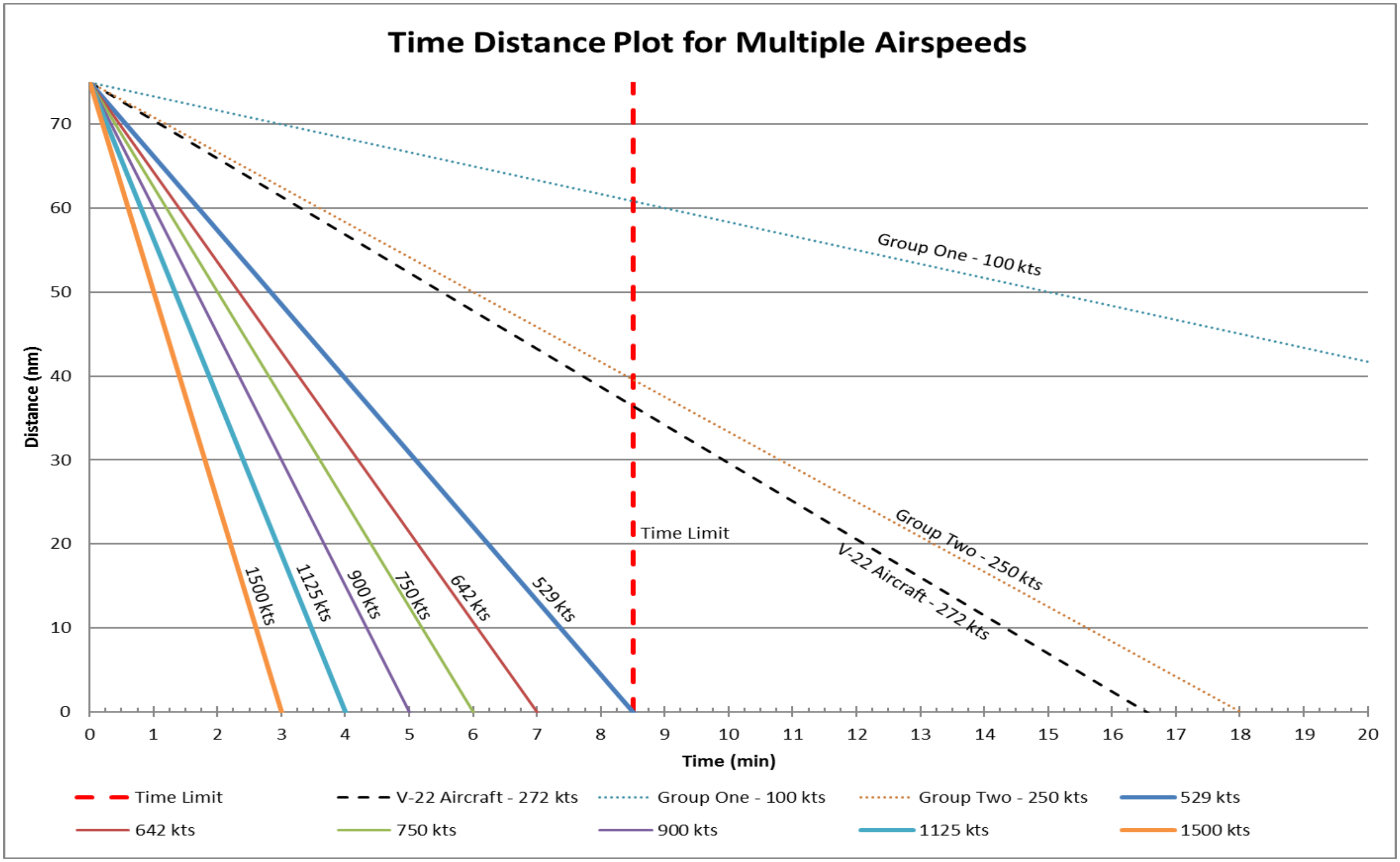


Figure 8. Time Distance Plot for Multiple Airspeeds.

As can be seen in Figure 8, The V-22 aircraft travels the distance of 75 nm in 16.5 minutes; therefore, a UAS must be able to traverse the same distance in 8.5 minutes to meet the stakeholder's requirement. Group One and Two systems with speeds slower than the V-22 aircraft will not be able to arrive before the V-22. In order for a UAS to supplement the V-22 aircraft, the UAS must achieve speeds well beyond its capabilities.

In order for the UAS to travel that distance in the allotted time, it must maintain an average speed of 529 kts; however, this does not afford the UAS any time to gather information about the LZ and transmit back to the V-22 aircrew. For example, if the UAS were to travel at an average speed of 900 kts it would have at most 3.5 minutes to gather LZ data and transmit it back to the aircrew.

One possible solution to address this capabilities speed gap is to develop a two-stage system. The first stage would accelerate a UAS; and the second stage would be a UAS operating under its own power.

A. CONCEPTUAL DESIGN

Figure 9 is concept generated by the USMCWL, the figure is meant to serve as a concept on how to increase the speed of a Group One or Group Two systems while maintaining the principal of smaller systems.

This figure is concept generated by the USMCWL. It depicts an AIM-9X missile with the seeker head removed and substituted with an UAS.

Figure 9. Concept Illustration of a FASTISR System.
Source: USMCWL (2016).

The FASTISR system can be thought of as the union of two systems: a missile motor and a UAS. These systems can be evaluated through a functional decomposition. The functional decomposition is meant to be utilized as a method of breaking down the system into the base functions that it needs to accomplish for the whole system to function as a unit. The V-22 aircraft does not currently have the ability to launch missiles; therefore, if the V-22 is to use this type of system, it must be modified for this capability or it must have a different system launch the system and send the data to theV-22.

B. FEASIBILITY ANALYSIS

The concept provided by the USMCWL has the UAS being launched from a missile. Currently, the V-22 aircraft does not possess the ability to launch missiles. However, the U.S. Marine Corps does have other aircraft with that ability. The current aircraft operated by the U.S. Marine Corps with missile launch capability are

- F-35C “Joint Strike Fighter”
- AV-8B “Harrier”

- F/A-18 “Hornet”
- KC-130J “Harvest Hawk”
- AH-1Z “Cobra”

However, an article written by Joshua Stewart (2014) for the *Marine Corps Times* states that the Officials at Headquarters Marine Corps are considering arming and installing the V-22 with greater weapons capability. The article mentions that Marine air-ground tasks forces will use the newly armed V-22 aircraft; specifically, the units that provide security support and embassy evacuation in Iraq, South Sudan, and Libya. Figure 10 is a photo of the V-22 aircraft with the added modification of a belly-mounted machine gun.

Figure 10. 7.6 mm Belly-Mounted Machine Gun on V-22 Aircraft. Source: U.S. Marine Corps.

As noted in the Stewart article, Loren Thompson, the chief operating officer of the Lexington Institute mentioned that the V-22 aircraft could be easily modified with

hardpoints, the devices utilized to carry missiles on the outside of aircraft, to carry either GPS or other types of munitions (Stewart 2014).

The belly-mounted machine gun mentioned in article from the *Marine Corps Times* is one example that it is feasible for the V-22 aircraft to carry exterior mounted munitions in the future.

C. REQUIREMENTS ANALYSIS

A model rocket kit was purchased to fulfill the requirements of a two-stage system; the rocket kit purchased was a "1/2 Scale Patriot Missile" manufactured by Public Missiles, Ltd. Similarly, a UAS was not purchased; instead, an ATS was built.

The author scoped the stakeholder's requirements to determine if it is feasible for a UAS to be deployed from a rocket. These requirements will attempt to address those listed by the USMCWL.

- launch ATS with rocket assistance
- reach a minimum altitude of 2,500 feet above ground level (AGL)
- deploy ATS from rocket
- obtain ATS flight data
- obtain rocket flight data
- obtain video footage (optional)
- recover ATS
- recover rocket

D. FUNCTIONAL ANALYSIS

The requirements specified by the author were translated into specific functions that must be completed by both the rocket and ATS. These functions serve as the FBL for the prototype.

1. Rocket Functional Analysis

The functions that must be accomplished by the rocket are as follows:

- Generate Vertical Impulse
- Store Glider
- Deploy Glider
- Record Flight Data
- Land

2. Aerodynamic Test Set Functional Analysis

The functions that must be accomplished by the ATS are as follows:

- Record Flight Data
- Record Imagery
- Land

The functions that have been listed are by no means all inclusive. Once the baseline functions have been listed, a functional decomposition is completed.

E. FUNCTIONAL DECOMPOSITION

The functional decomposition identifies which components or subsystems accomplished the functions set forth in the functional analysis. Additionally, it will act as a continuation of the functional analysis to discover overlooked or omitted functions.

1. Rocket Functional Decomposition

The purpose of the rocket is to propel the ATS beyond its maximum speed. Using the rocket in this manner will allow for greater ranges to be obtained, as well as determining if the ATS can withstand the forces associated with a rocket launch. The rocket will lift off from designated launch site, reach apogee (the highest vertical point), deploy a parachute, and return safely to the ground all while continuously transmitting position data and collecting on board flight data. Figure 11 illustrates the functional decomposition of the rocket.

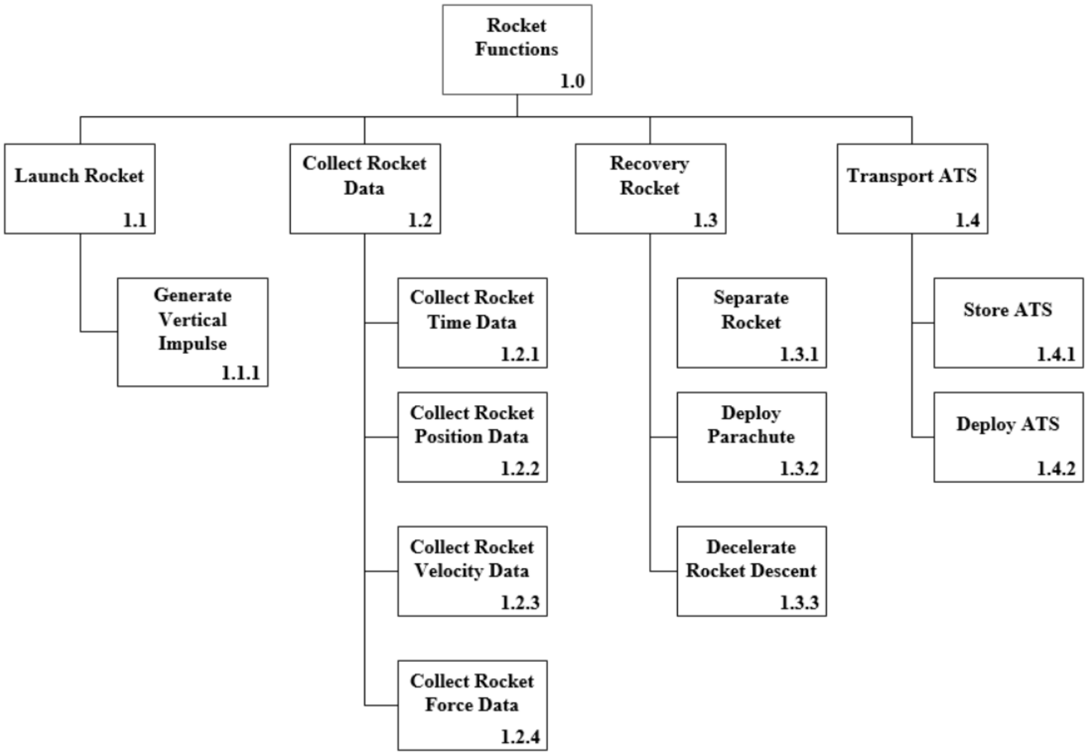


Figure 11. Rocket Functional Decomposition.

2. Aerodynamic Test Set Functional Decomposition

The purpose of the ATS is to function as a substitute for an UAS. It has characteristics similar to that of a UAS; however, it will not have any propulsion. The ATS will possess an onboard GPS, camera, and avionics suite. The ATS will deploy from within the rocket at apogee and return safely to the ground while continuously transmitting position data and collecting on board flight data. Figure 12 illustrates the functional decomposition of the aerodynamic test set.

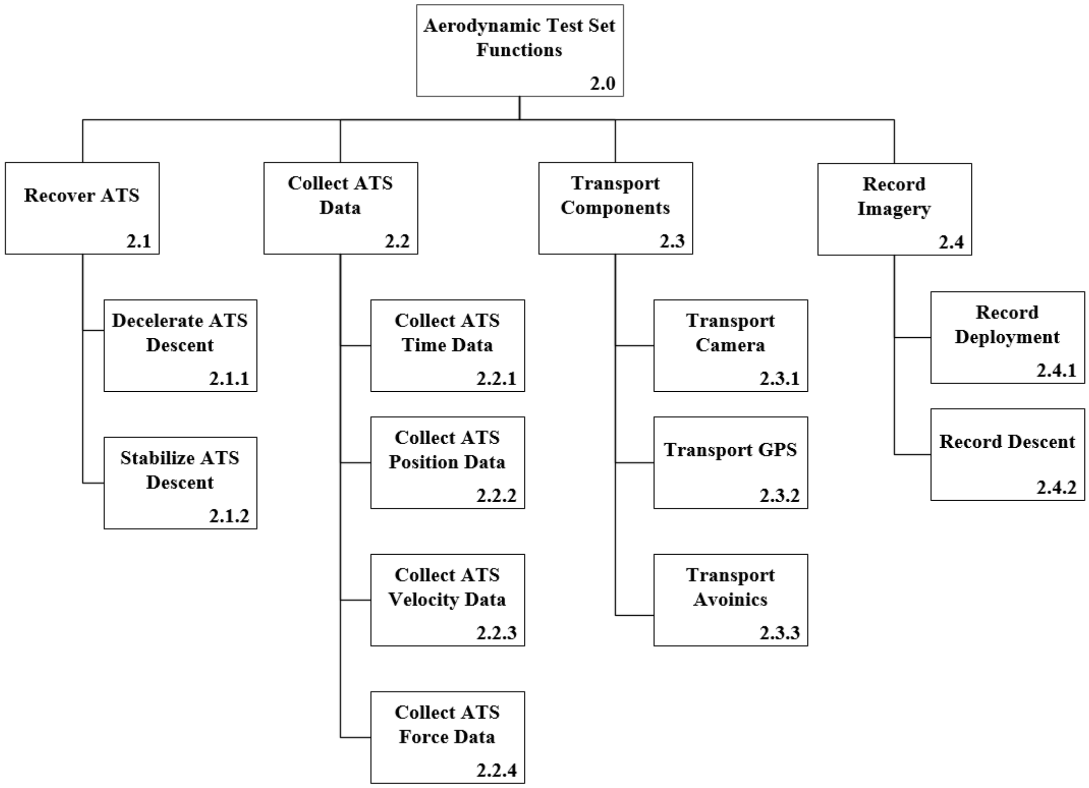


Figure 12. Aerodynamic Test Set Functional Decomposition.

F. TRACEABILITY

A DoDAF traceability matrix (SV-5) was used to depict the line between the operational activities and the associated systems (Dam 2006). The utilization of a SV-5 ensures that there are the appropriate components or subsystems to accomplish the specified functions.

1. Rocket Traceability Matrix

The rocket will be required to accomplish certain operational activities; these activities are broken down into specific system functions. The system functions and component or subsystem completing the function are tracked with an SV-5. Table 11 illustrates a completed SV-5 with associated functions and systems.

Table 11. Rocket Tractability Matrix (SV-5).

		System Functions									
		Collect Rocket Time Data	Collect Rocket Force Data	Collect Rocket Velocity Data	Collect Rocket Position Data	Deploy Parachute	Separate Rocket	Decelerate Rocket Descent	Generate Vertical Impulse	Store ATS	Deploy ATS
Component or Subsystem	Avionics	X	X	X							
	GPS				X						
	CPR Max					X					
	Ordnance						X				
	Parachute							X			
	Motor								X		
	Elevator									X	X

Functions that are to be completed appear in columns, and the systems completing the functions are located in rows. When a system completes a function, it is marked with an “X” at the intersection. Each function and system should be marked with at least one “X.” If a listed item is missing an “X,” then a system or function may be missing or not required

.

2. ATS Traceability Matrix

A traceability matrix was conducted for the ATS. The matrix is specific to the activities of the ATS. Table 12 illustrates a completed SV-5 with associated functions and systems.

Table 12. ATS Tractability Matrix (SV-5).

		System Functions										
		Collect ATS Time Data	Collect ATS Force Data	Collect ATS Velocity Data	Collect ATS Position Data	Decelerate ATS Descent	Stabilize ATS Descent	Transport Camera	Transport GPS	Transport Avionics	Record Deployment	Record Descent
Component or Subsystem	Avionics	X	X	X								
	GPS				X							
	Wings					X	X					
	Fuselage							X	X	X		
	Camera										X	X

Functions that are to be completed appear in columns, and the systems completing the functions are located in rows. When a system completes a function, it is marked with an “X” at the intersection. Each function and system should be marked with at least one “X.” If a listed item is missing an “X,” then a system or function may be missing or not required.

IV. FASTISR SYSTEM PROTOTYPING

The prototyping process consisted of constructing two ATSs and one delivery system. Additionally, a single ATS must be capable of fitting within the confines of the delivery system's payload section. The first ATS was constructed using a Mighty Mini Sportster (Flite Test 2017). The second ATS was constructed using reclaimed parts from a children's kite and the Mighty Mini Sportster. While both test sets may differ, each encompassed of the same four components: airframe, GPS, altimeter, and camera. The components used in the construction of the ATSs will be described in this chapter.

A. DELIVERY SYSTEM

The intended delivery system was a "1/2 Scale Patriot Missile" rocket kit purchased from Public Missiles, Ltd. (see Figure 13). This system is meant to act as a substitute for what the V-22 aircraft would use to launch the FASTISR system.

Figure 13. 1/2 Scale Patriot Missile. Source: Public Missiles, Ltd (2017).

Note that a Patriot Missile's primary mission is long-range air-defense (Army Technology 2017); it was not intended to be launched from an aircraft. However, the dimensions of the delivery system are very close to two air-launched missile systems

currently in operation, specifically the AGM-65 and AIM-120, and the feasibility analysis showed there is a possibility that the V-22 may receive the capability to launch missiles in the future. Table 13 is a side-by-side comparison of the two missile systems to the delivery system.

Table 13. Comparison of Delivery System to Nearest Air-Launched Missiles. Adapted from Parsch (2008a and 2008b).

	Delivery System	**AGM-65**	**AIM-120**
Length	100 inches (254 cm)	98 inches (249 cm)	144 inches (366 cm)
Diameter	7.6 inches (19.3 cm)	12 inches (30.5 cm)	8 inches (20.3 cm)

Highlighted text depicts which dimensions most closely represent the delivery system.

Table 13 shows that the delivery system is slightly longer than the AGM-65 missile and smaller in diameter than the AIM-120 missile; however, the best approximation for the delivery system in this author's opinion is the AIM-120. The AIM-120 may be longer than the delivery system. Although, it is this increase in length that will allow for looser constraints when designing the airframe that must be contained within. Given that the delivery system is smaller in diameter than the AIM-120 missile the airframe constructed will more closely represent what may fit within that missile.

Modifications were made to the rocket kit received from Public Missiles, Ltd. These modifications were made to allow for a greater payload capacity. They also encompass a custom elevator; this elevator was attached to the parachute of the delivery system. Once the delivery system's parachute is deployed, it will pull up the elevator and deploy the ATS. The conceptual drawing for these modifications can be seen in Figure 14.

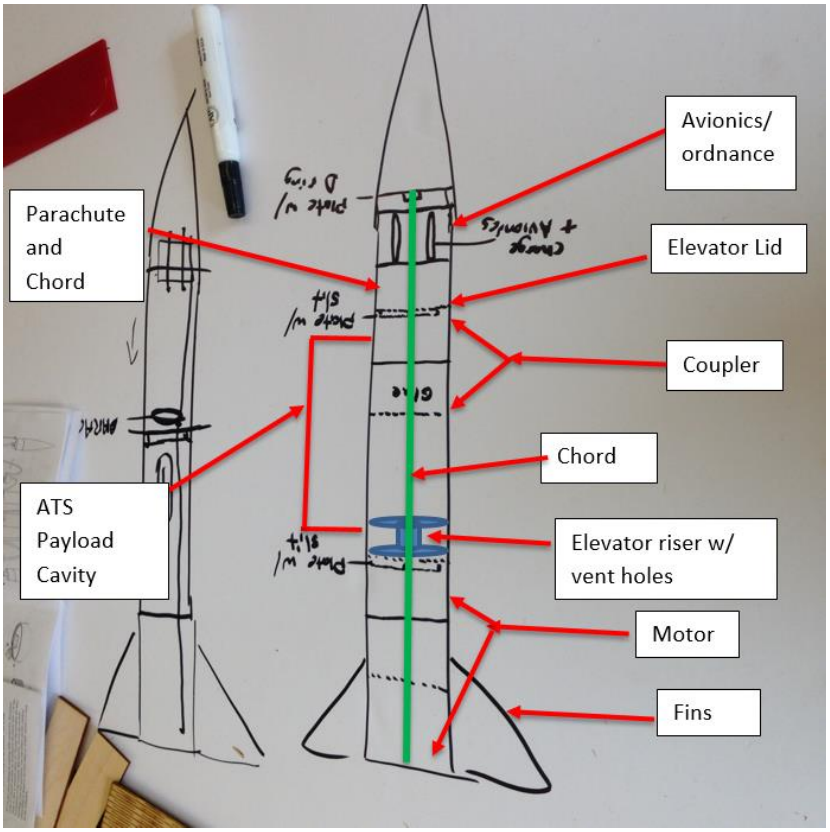


Figure 14. Conceptual Design of Delivery System Interior.

An exterior view of the fully completed delivery system can be seen in Figure 15. This system encompasses the interior conceptual design from Figure 14.

Figure 15. Fully Constructed Delivery System.

B. GLIDER AIRFRAME

The Mighty Mini Sportster was chosen because the fuselage has the ability to house the altimeter, GPS, and camera. The Flite Test line drawings of the Mighty Mini Sportster are shown in Figure 16.

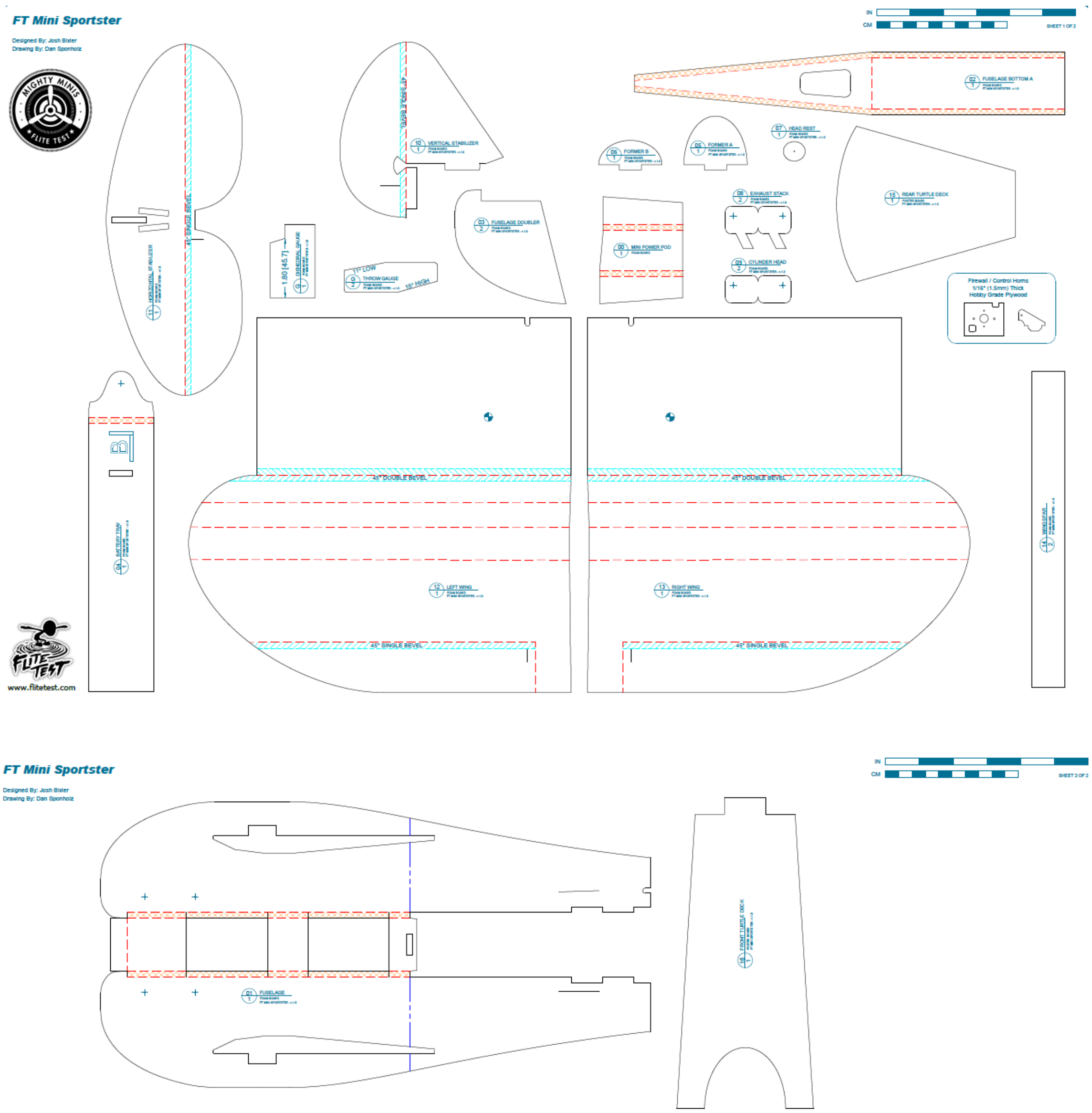


Figure 16. Flight Test Drawing of Mighty Mini Sportster.
Source: Flite Test (2017).

The materials used in construction of the Mighty Mini Sportster are water-resistant foam board, poster board paper, hot glue, and tape (Flite Test 2017). A fully assembled Mighty Mini Sportster can be seen in Figure 17 with dimensions in Table 14.

Figure 17. Mighty Mini Sportster. Source: Flite Test (2017).

Table 14. Mighty Mini Sportster Dimensions. Source: Flite Test (2017).

Wingspan	23 inches (58.4 cm)
Length	17 inches (43.2 cm)

As can be seen from the dimensions in Table 14, the wingspan is larger than the diameter of the delivery system. As a result, modifications must be made to design to accommodate the 7.6-inch diameter of the delivery system. Upon further inspection, it was realized that the elevators of the design are also greater than what the delivery system can accommodate. In order for the design to fit within the confines of the delivery system, a custom hinge was constructed to allow for the wing to fold, thus reducing its storage area. Additionally, the vertical stabilizer and elevator were modified according to the space constraints.

1. Glider Modified Wings

The material for the new wings was changed from water-resistant foam board to Readi-Board foam board manufactured by R. L. Adams Plastics, Inc. The reason for this

change is that there were dozens of sheets already on hand from previous projects. It must also be noted that this new material is not as sturdy as its water-resistant counterpart.

The new wings were constructed using a computer-aided-drafting (CAD) software called CorelDraw. The modified line drawings where then cut from the foam board using a Spirit GLS laser cutter. See Figure 18.

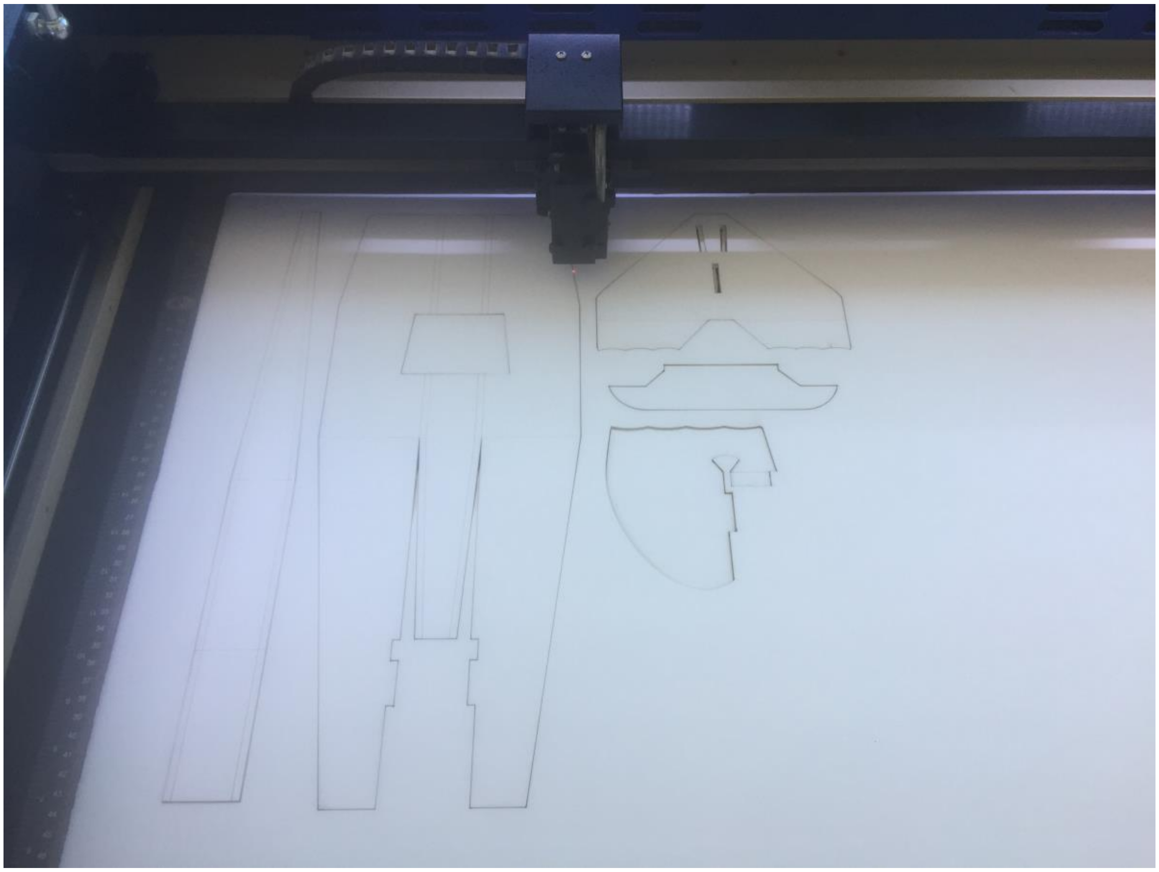


Figure 18. Modified Wings Being Cut by Spirit GLS Laser Cutter.

The laser cutter has the ability to cut to different types of material. Since the material is of different thicknesses and densities, not all the settings will be the same. The power and speed used for the laser can be modified by changing the software settings of the printer (Beall and Henderson 2016). For example, in order to achieve a full-score cut on foam board the laser cutter was set at 50% speed and 100% power; however, a full-score on 1/8-inch acrylic was set to 3% speed and 100% power. Additionally, the laser

can recognize different types of cuts based upon the colors used in the line drawings; a full-score cuts are indicated by black, half-score by red, and raster cuts by blue. The modifications to the wing design can be seen in Figure 19.

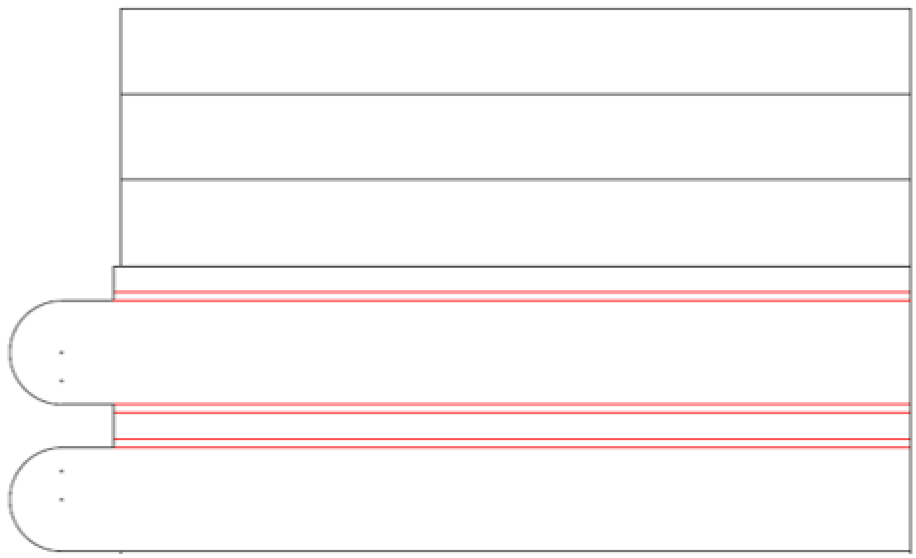


Figure 19. Modified Line Drawings for Single Wing.

This new design allows for each wing to be constructed from a single piece of foam board. It will also accommodate a hinge, which will allow for the wings to be folded towards the rear of the airframe. Given that this new foam board is not as sturdy, the interior portion of the wing was filled with additional pieces of foam board to give it rigidity. However, the interior pieces of foam cannot extend the full length of the wing because the wing must accommodate a folding hinge. Therefore, the weakest portion of the wing was where the interior foam and hinge meet. As a result, a brace constructed of wood was added to the upper and lower surfaces of the wing to give it additional support. The line drawing for the wooden wing supports can be seen in Figure 20.

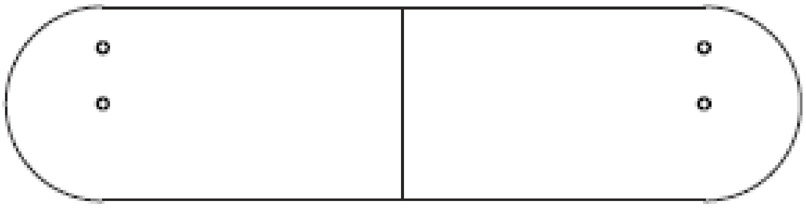


Figure 20. Line Drawings for Wooden Wing Support.

The fully constructed wing with interior foam support and wooden support braces can be seen in Figure 21.

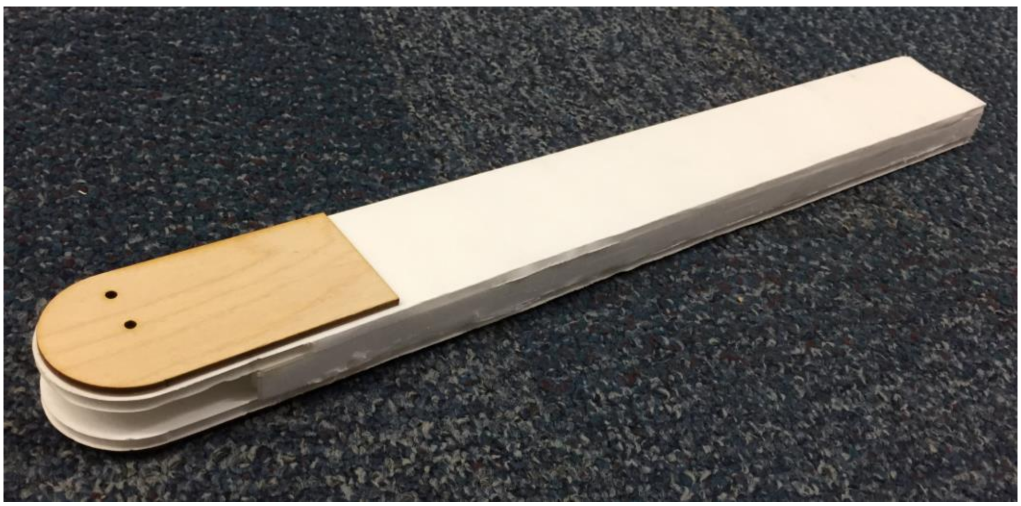


Figure 21. Fully Constructed Wing with Wood Supports.

2. Airframe Modifications

The new airframe was also constructed and modified using CorelDraw. The new airframe accommodates different shaped wings as well as a custom acrylic hinge. The modifications to the airframe design can be seen in Figure 22.

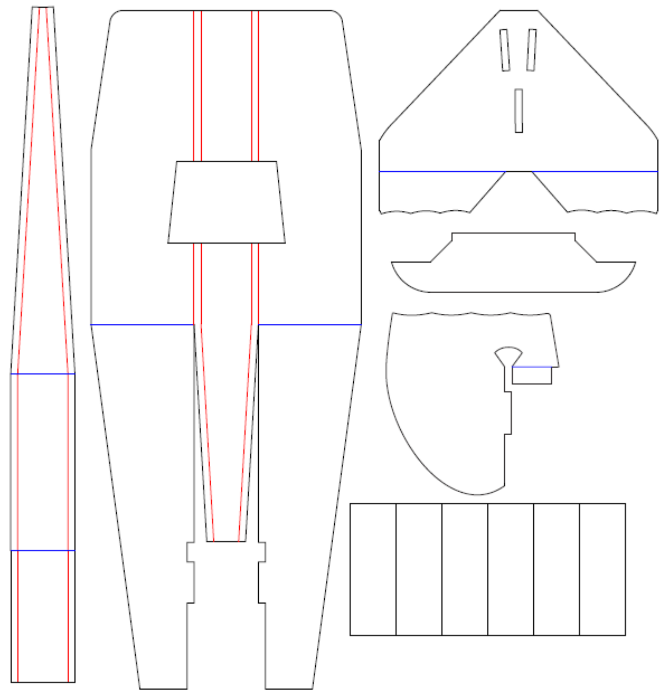


Figure 22. Modified Line Drawings for Glider ATS.

3. Custom Folding Wing Hinge

The custom folding wing hinge was also constructed by cutting a 1/8-inch sheet of acrylic plastic the laser cutter. The line drawing for the custom hinge can be seen in Figure 23.

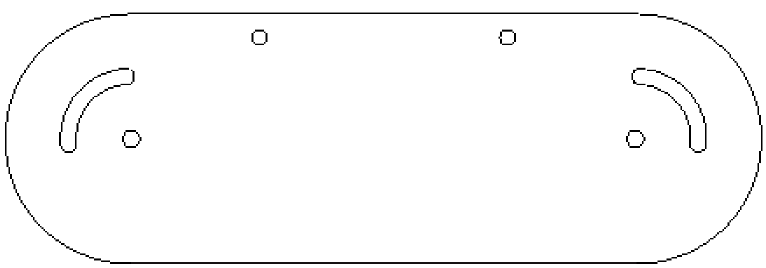


Figure 23. Line Drawing for Custom Folding Wing Hinge.

The hinge will allow for the ATS wings to be stowed under tension with a rubber band in the folded position; then upon exit from the delivery system, they will spread from the release of the tension. The entire folding wing hinge will consist of two hinges,

a top and bottom. Wooden bamboo rods were inserted through the newly designed wings and routed through the hinges. The outermost rods were connected by way of rubber bands to produce tension. The final construction of the hinge without wings attached can be seen in Figure 24.

Figure 24. Fully Constructed Top and Bottom Hinge with Foam Separator.

4. Modified Glider ATS

The newly modified ATS can now fit within the payload section of the delivery system. The components used were housed within the fuselage of the airframe. Figure 25 shows the modified ATS in its different configurations; the associated dimensions can be found in Table 15.

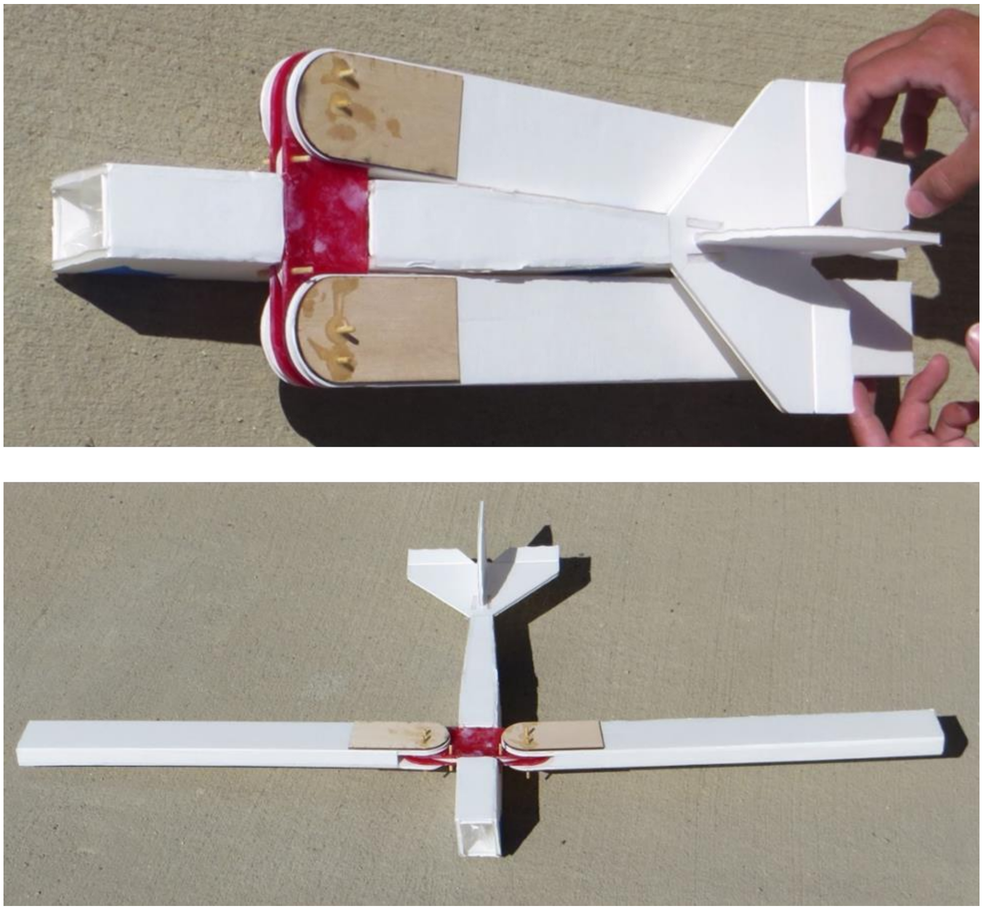


Figure 25. Glider ATS Configurations.

Table 15. Glider ATS Dimensions.

Wingspan (Extended)	37.5 inches (95.3 cm)
Length (Extended)	18 inches (45.7 cm)
Wingspan (Folded)	6.5 inches (16.5 cm)
Length (Folded)	22 inches (55.9)

As can be seen from Table 19, the dimensions of the Glider ATS are similar to those of Group One UASs. It is reasonable to assume that given increased funding, an already established Group One UAS may be modified or used in place of the ATSs.

C. FLYING WING AIRFRAME

The second ATS constructed was a flying-wing airframe. This was constructed by using the fuselage from the modified Mighty Mini Sportster, pieces of folding plastic from a children's kite, and reclaimed fabric from a parachute. The frame of the flying-wing was built by routing the plastic from the kite through the existing wing slots of the fuselage and then sewing fabric around the frame. Figure 26 shows the flying-wing ATS in its extended configuration.

Figure 26. Flying-Wing ATS.

The flying-wing ATS does not have a folded configuration but rather a bended configuration. The ATS is bended by hand and inserted into the payload section and then extends to conform to the space allocated; the associated dimensions for extended wingspan and length are 24.5-inches (62.2-cm) and 21-inches (53.3-cm), respectively.

D. GLOBAL POSITIONING SYSTEM (GPS)

A GPS unit was installed into each ATS and the delivery system. The GPS unit used was a "Trackimo Universal GPS Tracker." This device is very lightweight, weighing only 1.4 ounces (Trackimo 2017). It also has the ability to operate on existing cellular networks allowing it to be tracked via a proprietary application (Trackimo 2017). An image for the Trackimo GPS can be seen in Figure 27; the associated specifications for the device can be found in Table 16.

Figure 27. Trackimo GPS. Source: Trackimo (2017).

Table 16. Specifications for Trackimo GPS. Source: Trackimo (2017).

Length	1.8 inches (47mm)
Width	1.6 inches (40 mm)
Height	0.7 inches (17mm)
Weight	1.4 ounces (42 g)
Battery Active Time	48-96 hours
Update Rate	Once per minute

E. ALTIMETER

The altimeter used for the ATSs and delivery system were a "Raven Altimeter," manufactured by Featherweight Altimeters, LLC. This altimeter was chosen for its ability to record robust amount of data and it also has a very small profile, 1.80-inch x 0.8-inch x 0.55-inch (4.5-cm x 2.0-cm x 1.4-cm) (Featherweight Altimeters 2017). According to Featherweight, the altimeter has the ability to record the following data:

- 400 Hz axial accelerometer, +/- 70 Gs
- 200 Hz lateral accelerometer, +/- 35 Gs
- 20 Hz Baro data, +/- 0.3% accuracy!
- 20 Hz voltage on each of 4 deployment outputs
- 40 Hz output current
- 20 Hz high-precision temperature sensor
- 20 Hz for All flight events used for deployment logic.
- Flight counter
- All output program settings
- Accelerometer calibrations used during the flight
- Pad altitude above sea level (ASL)

An image of the lower and upper side of Raven altimeter can be seen in Figures 28 and 29, respectively.

Figure 28. Bottom Side of Raven Altimeter. Source: Featherweight Altimeters (2017).

Figure 29. Top Side of Raven Altimeter. Source: Featherweight Altimeters (2017).

Two altimeters were installed in the delivery system and one in each ATS. The delivery system altimeters are responsible for recording all flight data with respect to the system and possess the added feature of triggering an ordnance event. This event ignited the explosive charges within the system allowing parachute deployment. The altimeters were wired in such a way to provide redundancy for the explosive charges; a single altimeter would be able to trigger both explosive events in case of a single altimeter failure.

The altimeters within the ATSs recorded the flight data that would later be used to reconstruct the flight profiles. Each altimeter will be powered by two 3V batteries. The final construction of the altimeters can be seen in Figure 30.

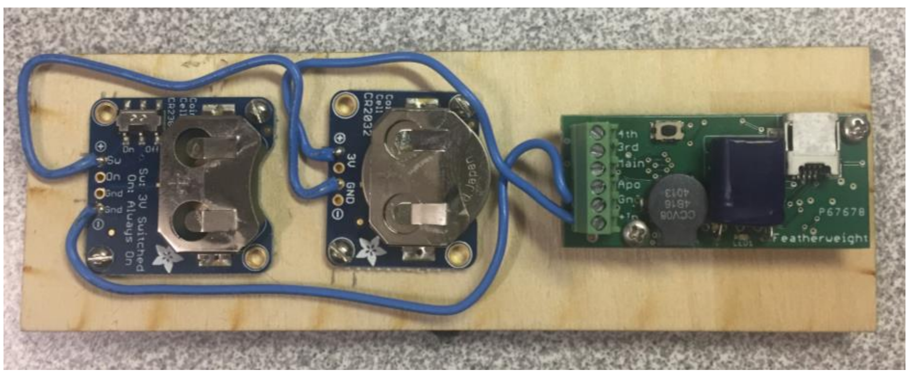


Figure 30. Final Mock-Up of Altimeter with Batteries Attached.

F. CAMERA

There were two cameras chosen to be used in the ATSs. Each camera comes with unique benefits, but the ultimate choice on primary and secondary cameras was based upon its size and weight.

1. Mobius One

The “Mobius One,” manufactured by Mobius Action Cam, served as the primary camera. The criteria used to determine this camera as primary was because of its small size and light weight. An image for the Mobius One can be seen in Figure 31; the associated specifications for the device can be found in Table 17.

Figure 31. Mobius One Camera. Source: Mobius (2017).

Table 17. Specifications for Mobius One Camera. Source: Mobius Action Cam (2017).

Length	2.4 inches (60 cm)
Width	1.4 inches (35 mm)
Height	0.7 inches (17mm)
Weight	1.3 ounces (38 g)
Video Length	3 min, 5 min, 10 min, and 15 min

2. Hero Session

The "Hero Session," manufactured by GoPro, served as the secondary camera. This camera was only planned to be used if there were issued with the primary camera's video recording. The drawbacks for this camera are its weight and size– both larger than the primary camera; however, it does possess increased video recording time. An image for the Hero Session can be seen in Figure 32; the associated specifications for the device can be found in Table 18.

Figure 32. Hero Session Camera. Source: GoPro (2017).

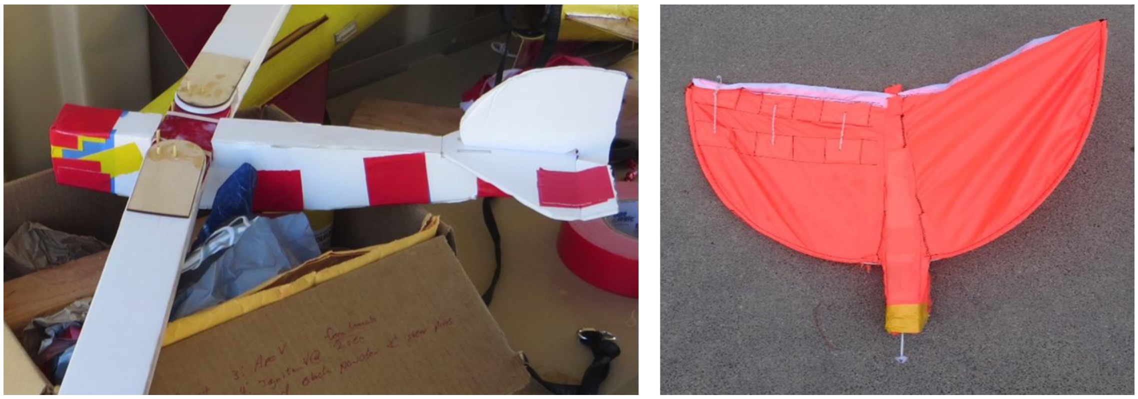
Table 18. Specifications for Hero Session Camera. Source: GoPro (2017).

Length	1 inch (25.4 cm)
Width	1 inch (25.4 cm)
Height	1 inch (25.4 cm)
Weight	2.6 ounces (74 g)
Video Length	Continuous 1 hour 45 min

G. FINAL CONSTRUCTION

Each prototype ATS was brought to the launch site without components installed. Once it was determined that the launch time was nearing, the components were then installed with the respective airframes and power sources switched to the ON position.

The cameras were mounted in the nose of the airframe with GPS and avionics mounted in the interior of the fuselage at or forward of the center of gravity. Once all components were mounted, the ATSs were secured with duct tape, if required. Fully completed ATSs can be seen in Figure 33.



The image on the left is of the fully assembled Glider ATS. The image on the right is of the fully assembled Flying-Wing ATS.

Figure 33. Fully Assembled ATSs.

V. PROTOTYPE FIELD TESTING

Upon completion of the prototyping phase, the testing phase started. The testing phase consisted of prelaunch and launch testing. Prelaunch testing was necessary to verify that hardware and software were working properly. The launch testing verified ability to launch, deploy ATS, and descend safely to the ground.

A. COMPONENT PRELAUNCH TESTING

Prelaunch testing was conducted for all the components of the delivery system and the ATSs. The testing was conducted at the Naval Postgraduate School (NPS) campus prior to arriving at the launch location in the Mojave Desert. This would allow for any corrections in hardware and software to be fixed in a controlled environment with the necessary equipment and replacement parts. Prelaunch testing consisted of verifying the hardware interfaces and software initialization was complete. Each system was setup as if it were going to be launch; once it was determined that each system was working satisfactorily, they were disassembled into a standby status.

1. Delivery System

The upper and lower portions of the delivery system were joined to the connector interface after the ATS was loaded. If the connection between the upper and lower portions to the interface were too tight, separation may not occur; thus not allowing the ATS to be deployed. If the connection was too loose, premature separation could occur; this would result in the ATS being deployed early exposing it high velocity winds of the delivery system. Finally, the nose of the delivery system was installed; upon installation, the hardware aspect of the delivery system was determined ready for launch.

2. Altimeters

Next, software prelaunch testing was conducted to ensure the altimeters were operational and aligned. The Raven altimeters were setup according to the manufacturer's specifications. After completing the initialization and setup, altimeters were disconnected

from the computer and power source removed. Finally, altimeters were placed in the avionics bay of the delivery system.

3. GPS Units

The next components tested were the GPS units; these components were tested both at the NPS campus and at the launch location. The GPS units were set up and tested according to the manufacturer's specifications to enhance battery life. The test process included use of a cellular phone, a phone application, GPS unit, and wireless signal. Utilizing a predefined location at both the NPS campus and launch location, each GPS unit was turned on to verify it was generating realistic position data. All necessary systems were available during prelaunch testing but intermittent at the launch location. The degradation of wireless reception at the launch location was determined to be an acceptable risk.

4. Cameras

The Mobius One and Hero Session camera were tested; the tests included the ability for each camera to record both audio and video data, impact testing, and transfer capability following impact testing. Once it was determined that each camera was recording properly, they were subjected to an impact test. This test consisted of inserting the cameras into the ATSs and thrown off a five-story building, this was meant to simulate the impact that the cameras could be subject to on landing. Both cameras and ATSs were recovered and data analyzed. Upon inspection, the data collected from both cameras was non-damaged; however, it seemed that when the Hero Session camera was installed the descent rate of the ATS was increased. This was expected because the camera weighs twice as much as its counterpart.

B. FIELD TESTING

All field tests were conducted at the Friends of Amateur Rocketry (FAR) launch site located in the Cantil, CA, situated in the Mojave Desert. Upon arriving at the launch site, the delivery system and ATSs were reassembled and readied for launch. Two launches were conducted. Each launch was conducted using the following sequence:

- delivery system altimeter power sources connected
- delivery system altimeter power switches turned to the OFF position
- ATS altimeter power source connected
- ATS altimeter power source switched to the ON position
- GPS unit loaded into the ATS
- ATS GPS unit switched to the ON position
- camera loaded into the ATS
- ATS camera switched to the ON position
- ATS airframe secured with duct tape
- ATS loaded into delivery system
- GPS unit loaded into the delivery system
- delivery system GPS unit switched to the ON position Ordnance loaded into delivery system
- delivery system upper, lower, and nose sections secured
- delivery system transported and loaded onto launch pad
- delivery system altimeter power switches turned to the ON position

Figure 34 shows the delivery system ready for launch with all switches, altimeters, cameras, and GPS units in the ON position.

Figure 34. Delivery System Readied for Launch on Pad.

The first launch was conducted using the glider ATS. The ordinance operator inserted the fuse and launched the delivery system. The system left the launch pad after the first ordnance event at time zero. Audio and video footage from the Mobius One camera was unavailable from this launch; it is assumed that this occurred because the delivery system was on the launch pad for an extended period exceeding the maximum recording time of the device.

The second launch was similar to the first. However, a few adjustments were made; the adjustments are as follows:

- dual ATS deployment
- glider ATS contained Hero Session camera
- flying-wing ATS contained Mobius One camera
- flying-wing ATS did not contain an altimeter

Upon completion of the second launch, the altimeter data was examined from the delivery system and the glider ATS. Since there was a camera change on the glider ATS, its descent rate drastically increased. As a result, it impacted the ground significantly harder and altimeter data was not recoverable. However, the Hero Session was able to

record both audio and video footage of the deployment and descent. Additionally, audio and video footage from the flying-wing ATS was not able to be recovered; it is again assumed that the camera reached its recording limit before launch occurred. Figure 35 is a picture taken of the delivery system launch from an UAV.

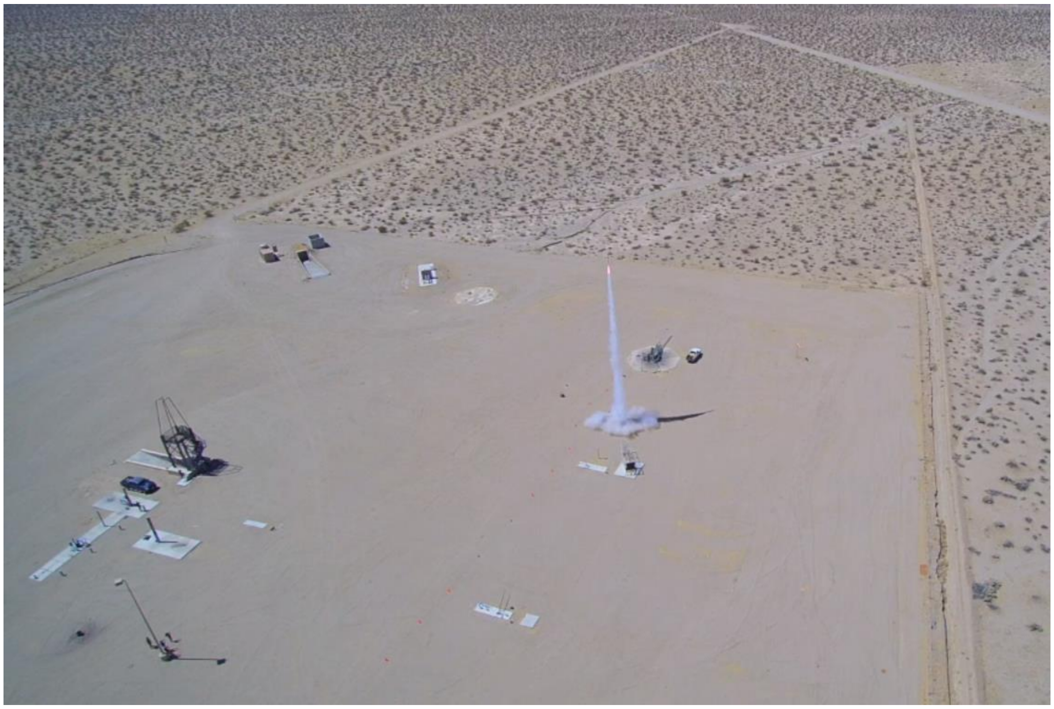


Figure 35. Delivery System Launch.

Once the delivery system reached maximum altitude, the ATSs were deployed. Figure 36 is a picture taken from the glider ATS upon its descent.

Figure 36. Aerial Photograph Taken from Glider ATS.

C. ANALYSIS

Upon recovery of the delivery system and glider ATS, the altimeters were removed and the data uploaded to a personal computer. After the data was analyzed, it was run through custom MATLAB script. This script is intended to plot various parameters to include:

- velocity measured in feet-per-second (ft/s)
- altitude measured in feet (ft)
- axial acceleration measured in G-forces (g)
- time measured in seconds (s)

The MATLAB script would also plot these parameters against a simulation that was created in RockSim9; the MATLAB script can be found in the Appendix. The RockSim9 simulation accepted user input to create a simulation that would attempt to mirror the actual launch. The primary user inputs for RockSim9 were for the rocket dimensions, weight, and atmospheric data at the launch site. The simulation was conducted the day before launch at the NPS campus; therefore, real-time atmospheric data at the launch site was unavailable and an approximation had to be made. A full plot

of the field test data against the simulation data can be seen in Figure 37; the figure is a plot of the delivery system, glider ATS, and RockSim9 data. The entire mission lasted approximately 130 seconds from ignition of the delivery system to glider ATS touchdown. A zoomed-in version of this plot covering the ascent portion can be seen in Figure 38; however, this figure only covers the significant events that span the first 15 seconds. There are multiple plot lines for the delivery system; this is because the data plotted was from both the accelerometer and barometer.

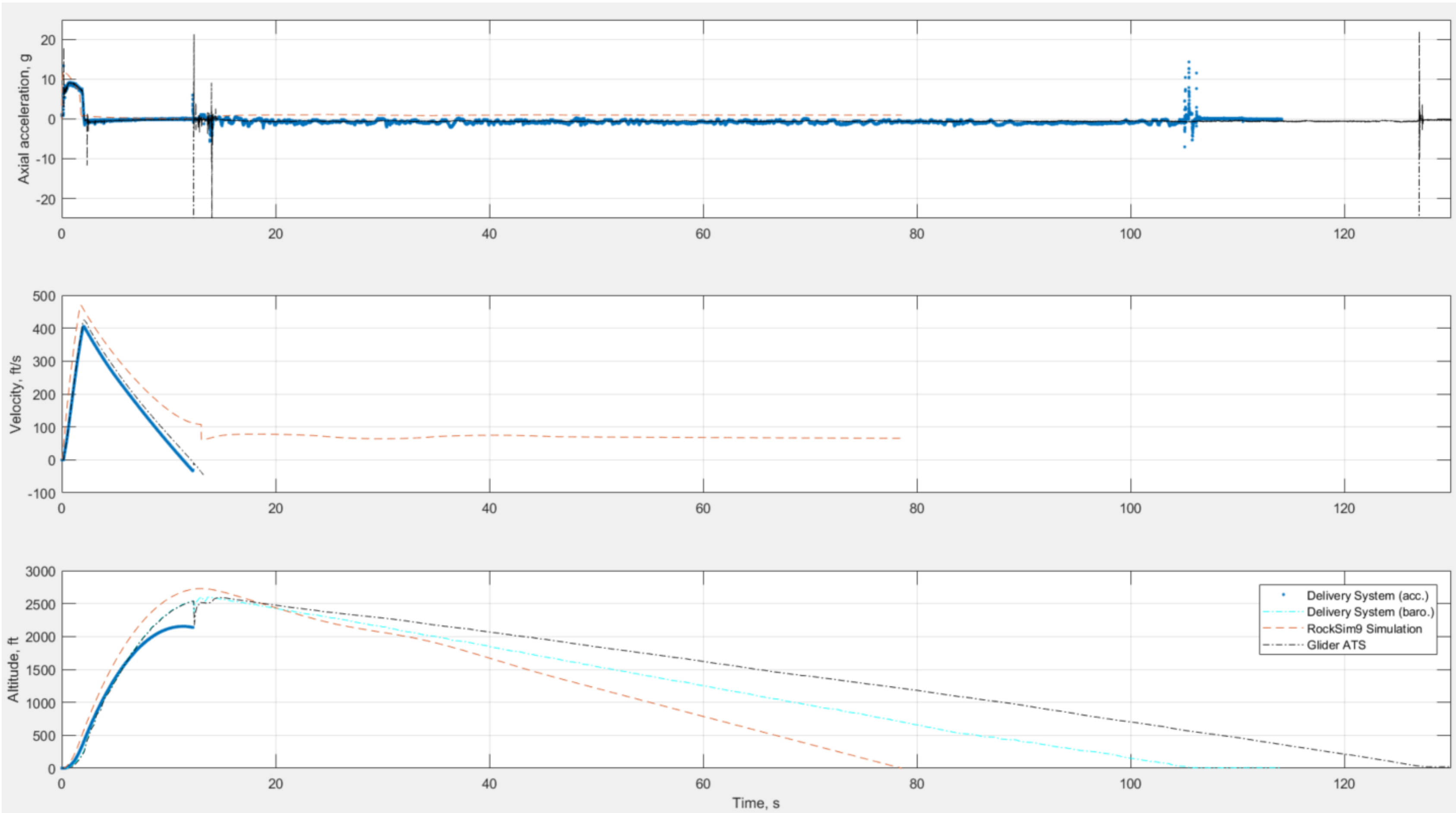


Figure 37. Full Data Plot for Field Test.

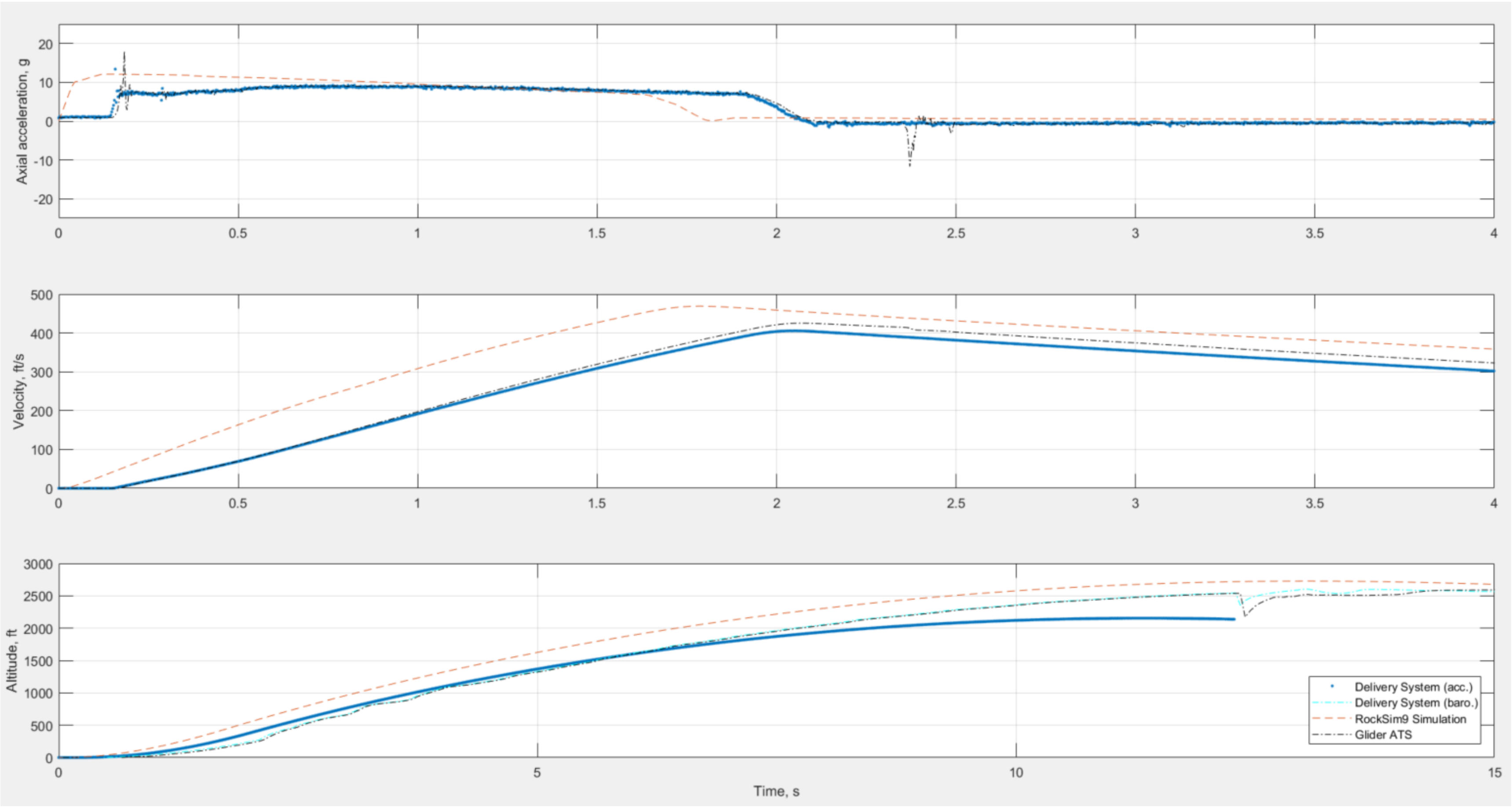


Figure 38. Zoomed in Data Plot for Field Test.

Utilizing MATLAB to parse the data, results showed that the glider ATS experienced 18.03 times the normal force of gravity (g) in its initial acceleration from the delivery system. The ATS also experienced its maximum g-force of 22.19 g upon its landing. Inspection of the ATS showed that the entire system experience minor cosmetic damage; subsequently, it was reusable for further testing. Additionally, using the data obtained from the barometer, the delivery system and glider ATS maximum altitudes were 2,603 feet. When compared to the RockSim9 simulation the difference in maximum altitudes is 124 feet; the assumption is that this difference can be attributed to changes in atmospheric conditions. The delivery system and ATS descended until impact on the Mojave Desert floor at 105 and 127 seconds, respectively.

VI. CONCLUSION AND FUTURE RECOMMENDATIONS

Based upon the information gathered about the candidate UASs, it can be seen that a single-stage system will not be able to meet the eight minute requirement set by the stakeholder. A two-stage system architecture offers the ability a UAS arrive at the intended destination in much shorter time periods; however, once a system is launched, it is considered disposable. Referencing the air-to-air and air-to-surface missiles discussed in this work, the associated cost of those missiles are hundreds of thousands of dollars; additionally, Group One UASs typically cost tens of thousands of dollars. As a result, the expected cost of a single FASTISR system would be proportional to the existing or new missile system utilized. Assuming such a system is implemented, the cost associated with using such a system would be much less than the cost of losing a single V-22 aircraft: approximately $89 million (Church 2015).

Furthermore, the data collected from the field test showed that the ATS experienced increased g-forces from the launch of the delivery system. Upon visual inspection of the COTS components, neither the avionics, GPS, cameras, nor ATSs showed any signs of failure as a result of multiple launches. While this peak g-load cannot be representative for the AIM-120 missile, logic would dictate that a military system would be designed in such a way to combat the g-forces experienced from a military launch and subsequent maneuvering.

As a result, it is the author’s opinion that the V-22 aircraft could indeed utilize a FASTISR system; assuming that it has been retrofitted to launch missiles or rockets.

This assessment can be utilized as a baseline to complement the inadequacies of current UASs. The use of a missile or rocket to propel the system will allow for increased range and extended on-station time. Additionally, the FASTISR system could be used to increase the flexibility of certain units that require ISR on their missions to bring it with them instead of waiting for in-theater assets.

The initial concept for a FASTISR system was intended to be utilized for a V-22 aircraft; however, it can be expanded to other applications. Unmanned aerial vehicle

swarms could utilize the principles in this work to increase their combat radius. The utilization of a rocket or missile to propel the swarm would allow them to get to objectives that are farther away more rapidly and preserve precious battery life that is lost in the transit.

Finally, the prototypes built for this research are simplistic; they do not have added feature of moveable control surfaces. It is recommended that if more research is to be conducted, subsequent prototypes should be built to accompany movable control surfaces, and an autopilot system.

APPENDIX. MATLAB SCRIPT

```
%% Import data from spreadsheet
% Script for importing data from the Raven and RocketSim spreadsheets
close all, clear all, clc

%% Import Raven data with the following data sets chosen:
% AxialAccelGs
% BaroAtm
% AltitudeAccelFt
% AltitudeBaroFtAGL
% VelocityAccelFtSec

[FileName,PathName]=uigetfile({'Raven 1 Flight 1.xlsx'},'Select the Raven 1 Flight 1
data file');
[~, ~, raw] = xlsread(horzcat(PathName,FileName));
raw(1,:)=[];
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};
R = cellfun(@(x) ~isnumeric(x) && ~islogical(x),raw); % Find non-numeric cells
raw(R) = {NaN}; % Replace non-numeric cells
data = reshape([raw{:}],size(raw));
  TimeAxialAccelGs = data(:,1);
  AxialAccelGs = data(:,2);
  TimeBaroAtm = data(:,3);
  BaroAtm = data(:,4);
  TimeAltitudeAccelFt = data(:,5);
  AltitudeAccelFt = data(:,6);
  TimeAltitudeBaroFtAGL = data(:,7);
  AltitudeBaroFtAGL = data(:,8);
  TimeVelocityAccelFtSec = data(:,9);
  VelocityAccelFtSec = data(:,10);

clearvars data raw R FileName PathName

%% Import Raven Glider data with the following data sets chosen:
% AxialAccelGs
% BaroAtm
% AltitudeAccelFt
% AltitudeBaroFtAGL
% VelocityAccelFtSec

[FileName,PathName]=uigetfile({'Glider Data.xlsx'},'Select the Glider Data data file');
[~, ~, raw] = xlsread(horzcat(PathName,FileName));
raw(1,:)=[];
```

```
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};
R = cellfun(@(x) ~isnumeric(x) && ~islogical(x),raw); % Find non-numeric cells
raw(R) = {NaN}; % Replace non-numeric cells
data = reshape([raw{:}],size(raw));
  TimeAxialAccelGsGlider = data(:,1);
  AxialAccelGsGlider = data(:,2);
  TimeBaroAtmGlider = data(:,3);
  BaroAtmGlider = data(:,4);
  TimeAltitudeAccelFtGlider = data(:,5);
  AltitudeAccelFtGlider = data(:,6);
  TimeAltitudeBaroFtAGLGlider = data(:,7);
  AltitudeBaroFtAGLGlider = data(:,8);
  TimeVelocityAccelFtSecGlider = data(:,9);
  VelocityAccelFtSecGlider = data(:,10);
clearvars data raw R FileName PathName

%% Import RocketSim data
[FileName,PathName]=uigetfile({'Patriot Rocket.xlsx'},'Select the Patriot Rocket
RockSim data file');
[~, ~, raw] = xlsread(horzcat(PathName,FileName));
raw(1,:)=[];
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};
R = cellfun(@(x) ~isnumeric(x) && ~islogical(x),raw); % Find non-numeric cells
raw(R) = {NaN}; % Replace non-numeric cells
data = reshape([raw{:}],size(raw));
  TimeSim = data(:,1);
  AccelerationSim = data(:,2);
  VelocitySim = data(:,3);
  AltitudeSim = data(:,4);
clearvars data raw R FileName PathName
%% Plot data
% SE3202Plot
%% Plotting data as is
figure('Name','1/2 Scale Patriot Missile Raw Data')
range = [0 130];
subplot(311)
plot(TimeAxialAccelGs,AxialAccelGs,'.'), grid, hold
plot(TimeSim,AccelerationSim,'--')
plot(TimeAxialAccelGsGlider,AxialAccelGsGlider,'-.k')
ylabel('Axial acceleration, g')
ylim(25*[-1 1])
xlim(range)
  subplot(312)
  plot(TimeVelocityAccelFtSec,VelocityAccelFtSec,'.'), grid, hold
  plot(TimeSim,VelocitySim,'--')
```

```
  plot(TimeVelocityAccelFtSecGlider,VelocityAccelFtSecGlider,'-.k')
  ylabel('Velocity, ft/s')
  xlim(range)
subplot(313)
plot(TimeAltitudeAccelFt,AltitudeAccelFt,'.'), grid, hold
plot(TimeAltitudeBaroFtAGL,AltitudeBaroFtAGL,'-.c')
plot(TimeSim,AltitudeSim,'--')
plot(TimeAltitudeBaroFtAGLGlider,AltitudeBaroFtAGLGlider,'-.k')
legend('Delivery System (acc.)','Delivery System (baro.)','RockSim9 Simulation','Glider
ATS','location','ne')
ylabel('Altitude, ft')
xlabel('Time, s')
ylim([0 3000])
xlim(range)


%% Plotting zoomed-in data
figure('Name','1/2 Scale Patriot Missile Ascent Data')
subplot(311)
plot(TimeAxialAccelGs,AxialAccelGs,'.'), grid, hold
plot(TimeSim,AccelerationSim,'--')
plot(TimeAxialAccelGsGlider,AxialAccelGsGlider,'-.k')
ylabel('Axial acceleration, g')
ylim(25*[-1 1])
xlim([0 4])
  subplot(312)
  plot(TimeVelocityAccelFtSec,VelocityAccelFtSec,'.'), grid, hold
  plot(TimeSim,VelocitySim,'--')
  plot(TimeVelocityAccelFtSecGlider,VelocityAccelFtSecGlider,'-.k')
  ylabel('Velocity, ft/s')
  xlim([0 4])
subplot(313)
plot(TimeAltitudeAccelFt,AltitudeAccelFt,'.'), grid, hold
plot(TimeAltitudeBaroFtAGL,AltitudeBaroFtAGL,'-.c')
plot(TimeSim,AltitudeSim,'--')
plot(TimeAltitudeBaroFtAGLGlider,AltitudeBaroFtAGLGlider,'-.k')
legend('Delivery System (acc.)','Delivery System (baro.)','RockSim9 Simulation','Glider
ATS','location','se')
ylabel('Altitude, ft')
xlim([0 15])
xlabel('Time, s')
ylim([0 3000])

%% Finding Max Values
```

```
Raven_max1 = max(AltitudeAccelFt);
Raven_max2 = max(AltitudeBaroFtAGL);
Sim_max1 = max(AltitudeSim);
Glider_max = max(AxialAccelGsGlider);

[row,col] = find(AxialAccelGsGlider==Glider_max);
Glider_max_time = TimeAxialAccelGsGlider(row,col);

[row,col] = find(AxialAccelGsGlider>=15);
Liftoff_G_time = TimeAxialAccelGsGlider(row(1),col(1));
Liftoff_G = AxialAccelGsGlider(row(1),col(1));

Max = max(Raven_max1,Raven_max2);
Difference = Max - Sim_max1;
Abs_Difference = abs(Difference);

fprintf('The max altitude from the Raven Accelerometer is %0.1f ft.\n',Raven_max1);
fprintf('The max altitude from the Raven Barometer is %0.1f ft.\n',Raven_max2);
fprintf('The max altitude from the RockSim9 simulation is %0.1f ft.\n',Sim_max1);
fprintf('The G-force from on the glider ATS from the delivery system ignition is %0.2f
g''s at %0.2f seconds.\n',Liftoff_G,Liftoff_G_time);
fprintf('The max G-force from the Glider Accelerometer for the entire mission is %0.2f
g''s at %0.2f seconds.\n',Glider_max,Glider_max_time);
fprintf('The difference in altitude from the simulation and the actual data is %0.1f
ft.\n',Abs_Difference);
```

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